Integrated flexible heating and cooling under climate uncertainty in a European energy systems model

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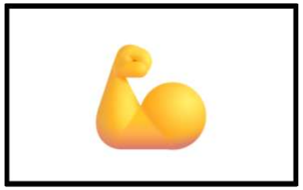
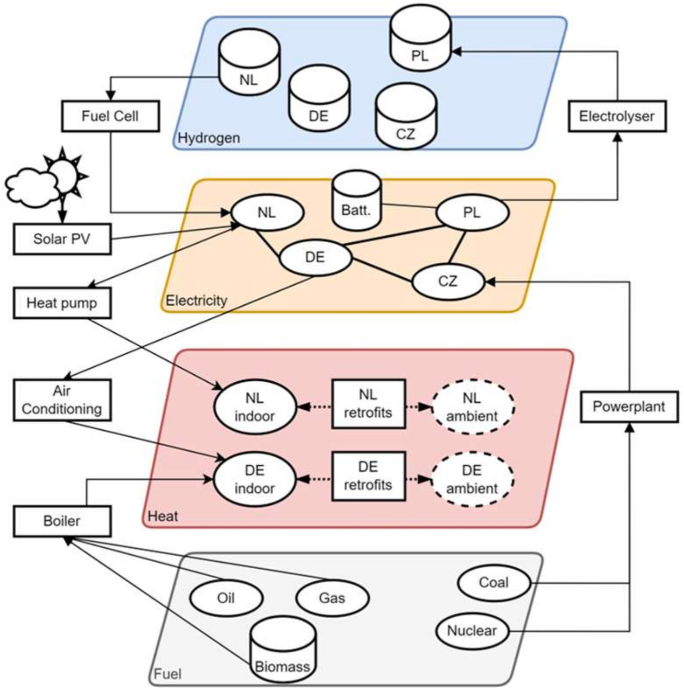
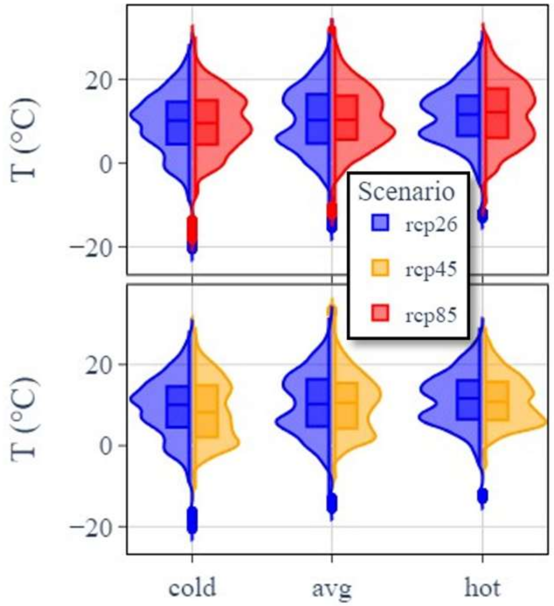
Outline





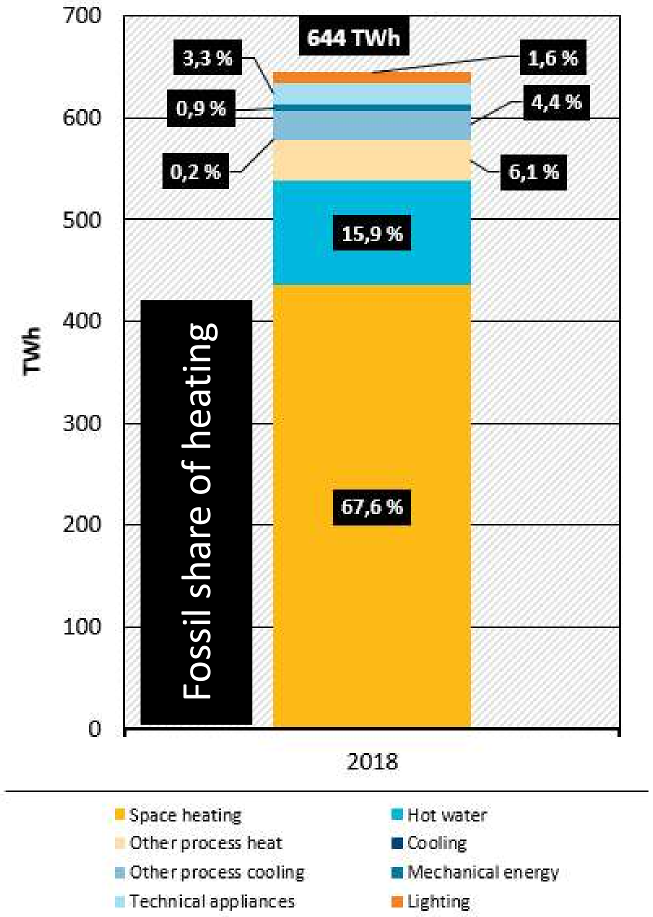


Implementing endogenous heat demand (+ retrofits)

Assessing climate uncertainty

Motivation

- Heating accounts for > 80% of energy use in households and is largely fossil fuelled (>75%)[1]
- Isolated optimisation might distort vision of desirable system
- A matter of perspective:
    - For home owners:
        - When does my retrofit pay off?
    - For nations:
        - How much less wind turbines are necessary?



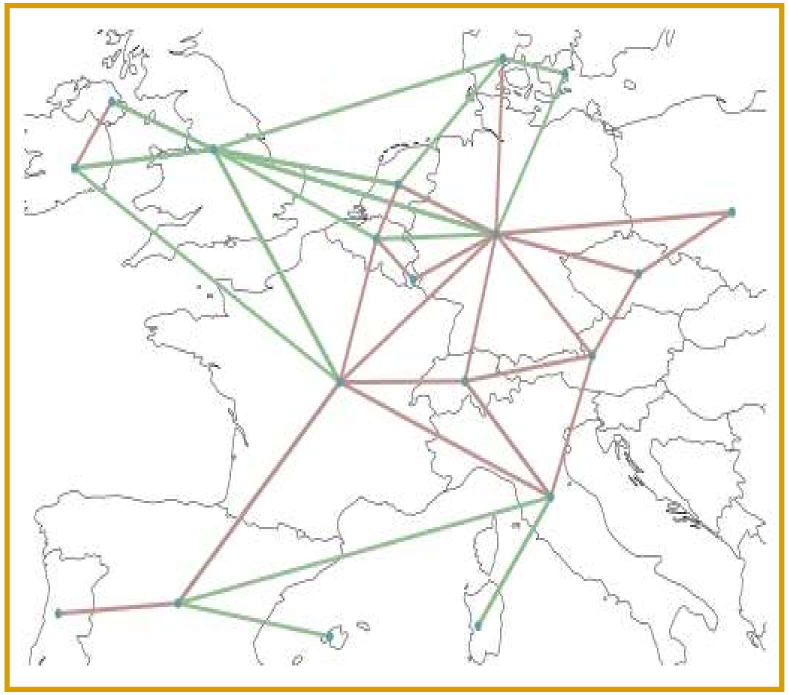
1. https://www.umweltbundesamt.de/daten/private-haushalte-konsum/wohnen/energieverbrauch-privater-haushalte#endenergieverbrauch-der-privaten-haushalte

Data & Method

Data

PyPSA-eur[1]

Electricity (Demand, generation, grid)

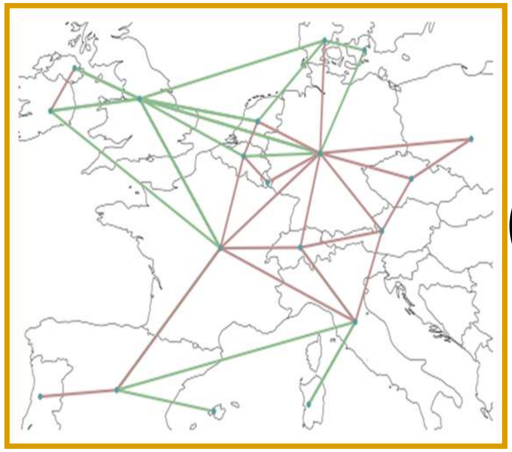


HotMaps[2]

Heat (Technologies, building data)

1. Hörsch et al. PyPSA-Eur: An open optimisation model of the European transmission system. Energy Strategy Reviews, 22:207-215, 2018. arXiv:1806.01613, doi:10.1016/j.esr.2018.08.012.
2. Pezzutto et al. Hotmaps, D2.3 WP2 Report – Open Data Set for the EU28, 2019

Method – Modelling framework: Backbone[3]



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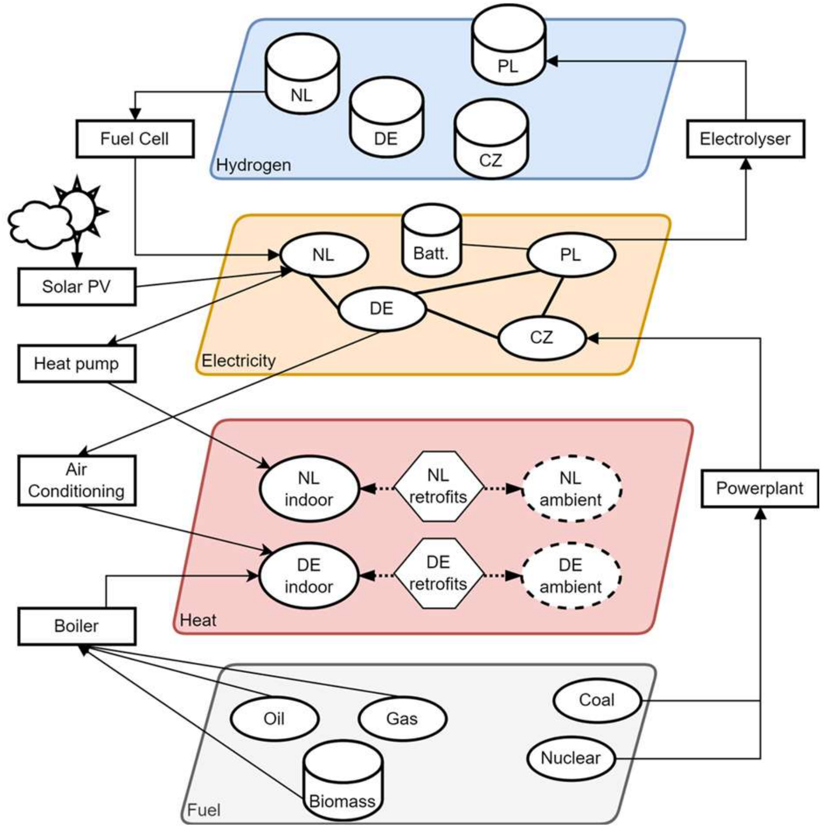
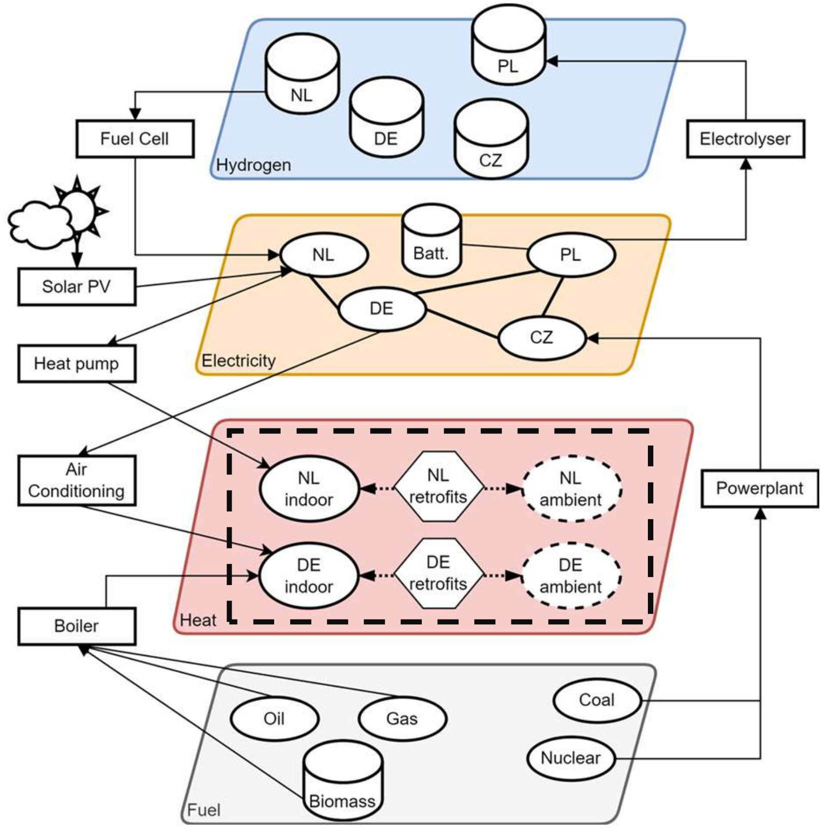


3. Helistö N, Kiviluoma J, Ikäheimo J, Rasku T, Rinne E, O'Dwyer C, Li R, Flynn D. Backbone—An Adaptable Energy Systems Modelling Framework. Energies. 2019; 12(17):3388. https://doi.org/10.3390/en12173388

Method – Modelling framework: Backbone[3]

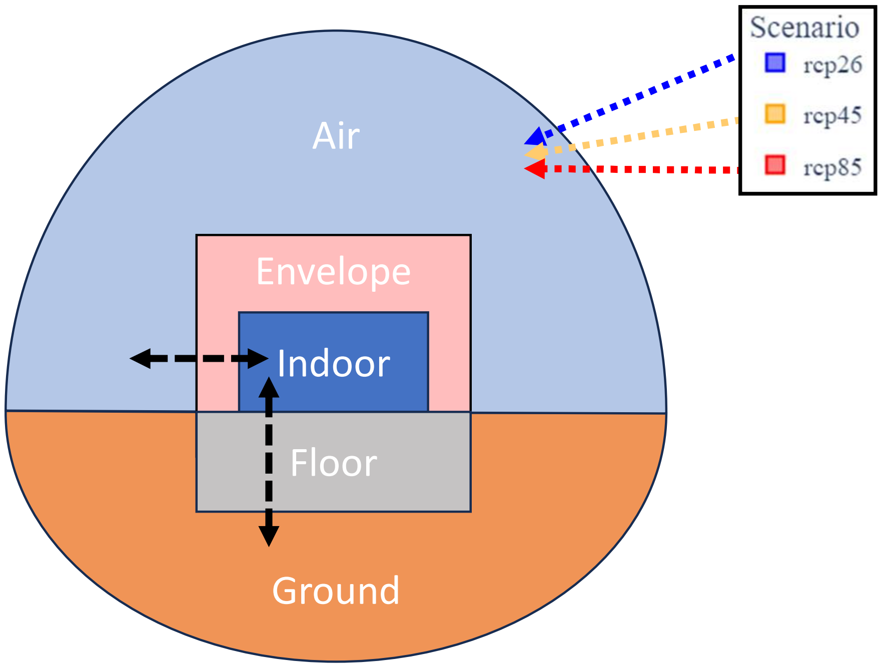
- **Grids** group **nodes** with similar types of energy
- **Nodes** can have a state and introduce demands
- **Units** transform energy between **nodes**



3. Helistö N, Kiviluoma J, Ikäheimo J, Rasku T, Rinne E, O'Dwyer C, Li R, Flynn D. Backbone—An Adaptable Energy Systems Modelling Framework. Energies. 2019; 12(17):3388. https://doi.org/10.3390/en12173388

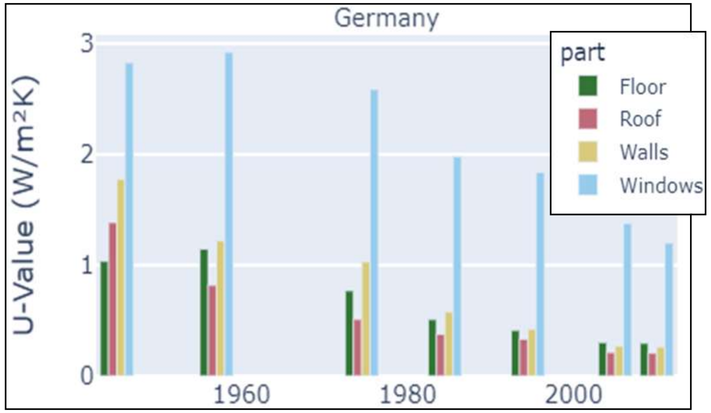
Method - Modelling heat transfer

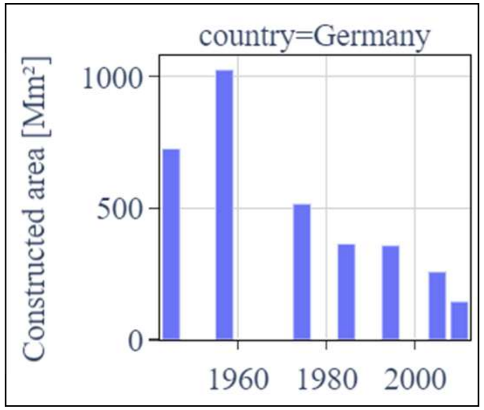
- Simplified representation of buildings
- Heat loss based on
    1) Temperature differences:
        - $T_t^i = 20°C \ \forall \ t$
        - $T_t^o \in$ {rcp26, rcp45, rcp85}
        - $T_t^g = f(T_t^o)$[5]
    2) Aggregated U-Values:
        - Envelope
        - Floor[5]

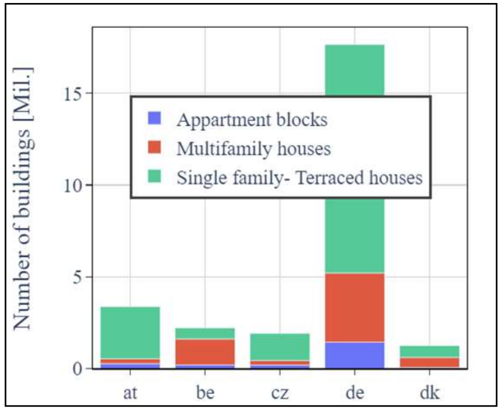


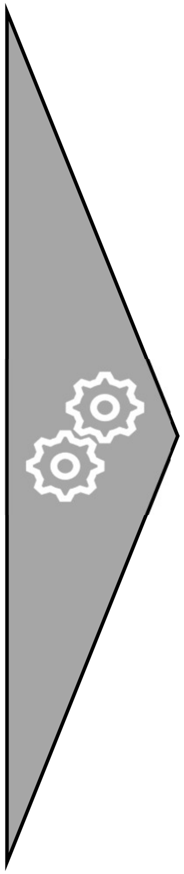
5. Kissock K, et.al (2013): Simplified model for ground heat transfer from slab-on-grade buildings. Build Eng 2013;119.

Method - Modelling heat transfer coefficients









Weighted avg. U-Values x Surface areas

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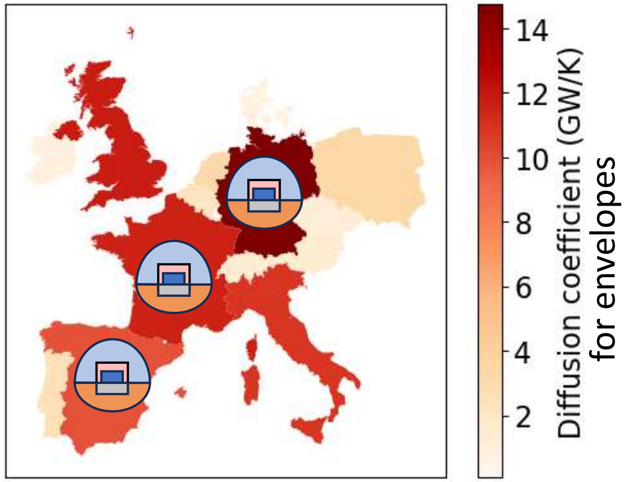
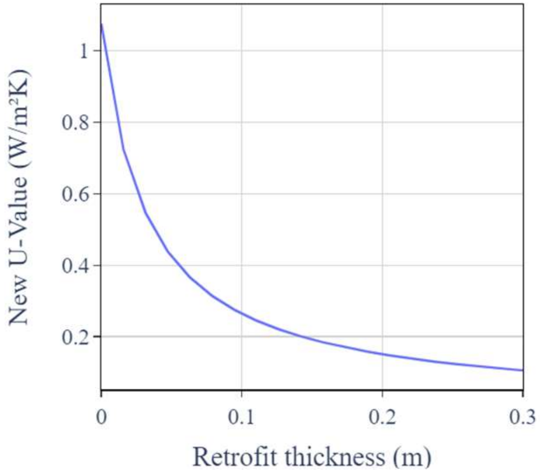
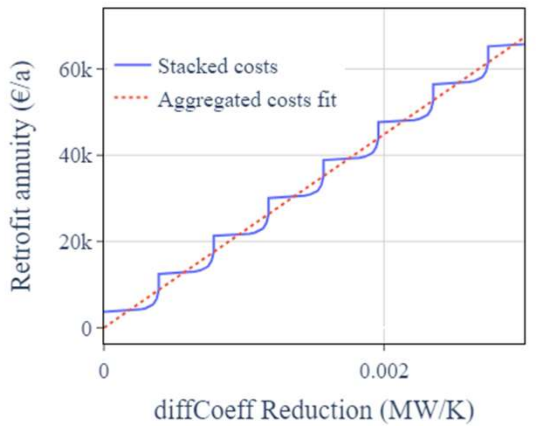


Analogous process for floors.

Method – Retrofits

- Retrofit **effect** determined with
  - Building areas, U-Values
  - Thermal conductivity of 0.035 (W/mK),
  - Max. thickness of 0.4 m,
- Retrofit **cost** determined with
  - WACC of 7%, 50-year lifespan
  - Cost data from 2015[6]
  - Stacking for country level indicators
- Applied to all model countries





"Retrofit order"

Country	Envelope area (Gm^2)	Envelope U-Value (W/m^2K)	Envelope retrofit cost (M€/MW/K)
pt	0.63	2.02	10.37
es	2.90	1.71	12.29
gb	3.88	1.52	13.90
be	0.72	1.48	14.32
nl	1.27	1.25	17.05
it	4.46	1.22	17.59
fr	4.91	1.18	18.18
ie	0.34	1.17	18.42
de	6.85	1.08	20.15
lu	0.04	1.06	20.50
at	0.68	1.02	21.26
cz	0.61	0.99	21.90
pl	1.75	0.94	23.25
dk	0.50	0.70	32.39

6. Hinz, E. (2015): Kosten energierelevanter Bau- und Anlagenteile bei der energetischen Modernisierung von Altbauten. Endbericht. 1. Auflage. Darmstadt: Institut Wohnen und Umwelt GmbH. 116 S. isbn: 9783941140509.

Scenarios & Results

Climate Scenarios

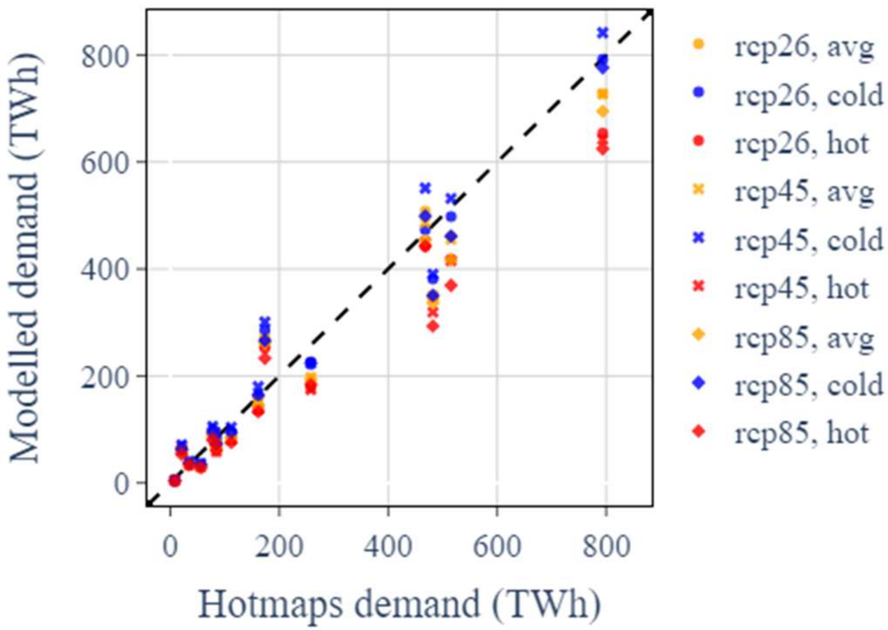
- Rcp 2.6
- Rcp 4.5
- Rcp 8.5

Model Scenarios

- Cost optimisation
  - With retrofits
  - Without retrofits
- 5 % remaining emissions
  - With retrofits
  - Without retrofits

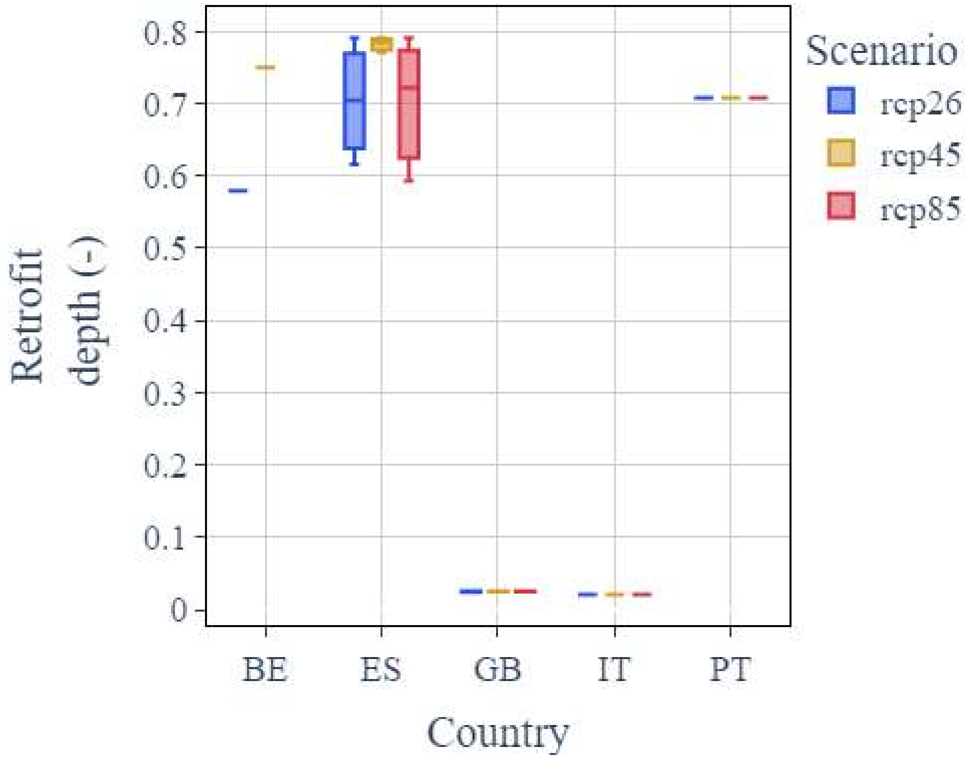
Results – Cost optimisation without retrofits

- Retrofits are "prohibited" by setting their price to 1e30 €
- No retrofits occur → Status quo model
- Demands are met reasonably well
  - On average a little too low, but this model doesn't include hot water.



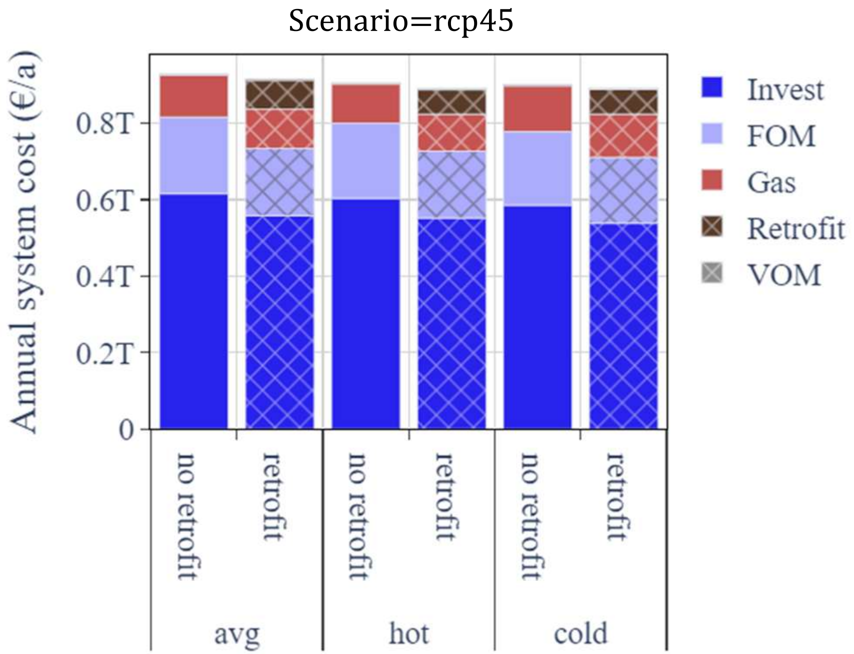
Results – Cost optimisation with retrofits

- Retrofits are limited (i.e. cannot reduce heat loss to 0 MW/K)
- Retrofitted countries roughly aligned with „retrofit order“
- Order is strengthened by overestimated AC-costs



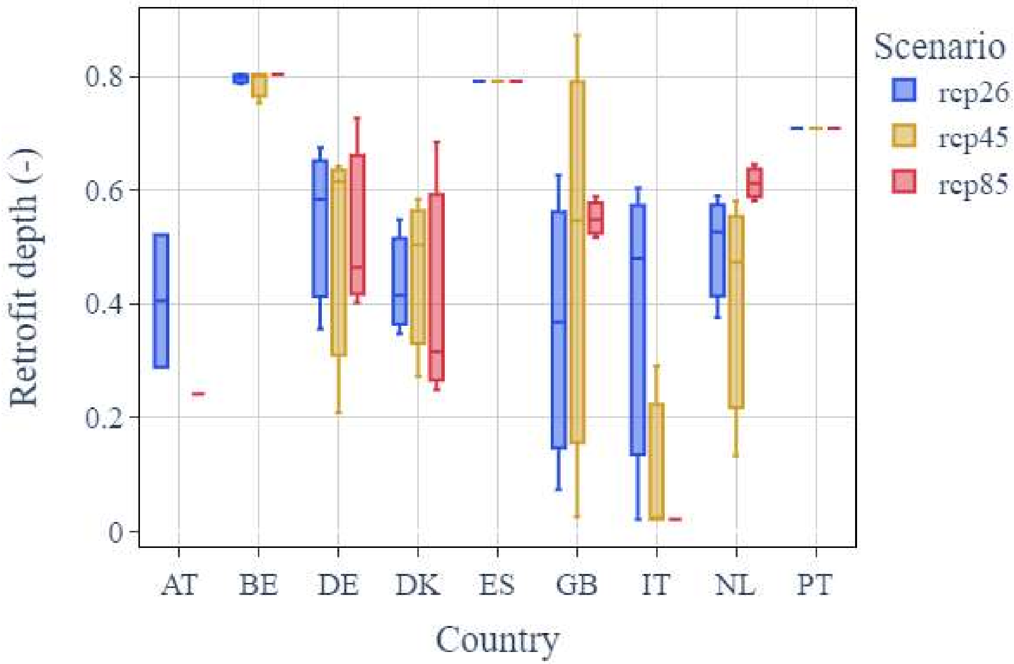
Results – Cost optimsation
Effect of retrofits on cost

- Cost components are reduced by around 10% each
- „Saving“ is mostly substituted by retrofit investment
- Retrofit option slightly reduces cost

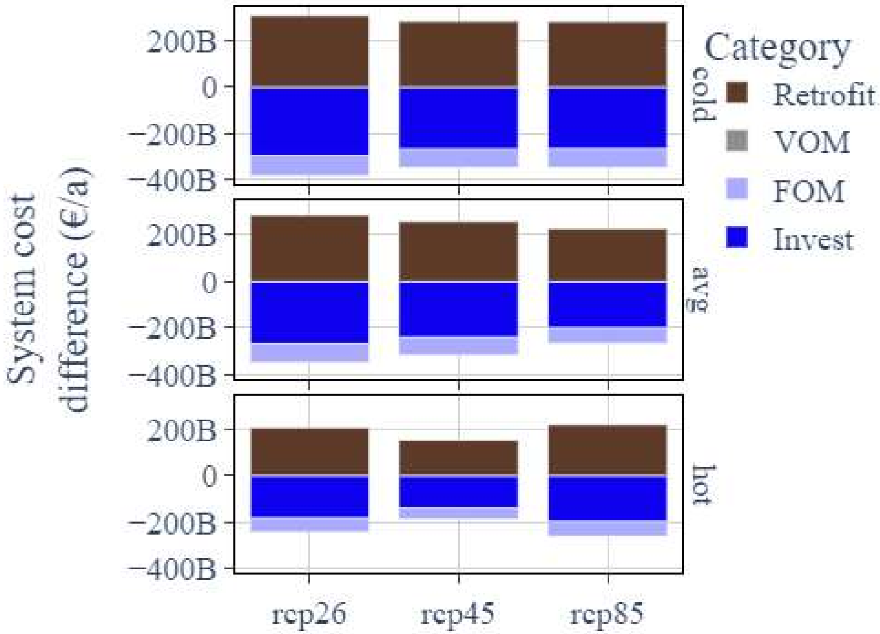


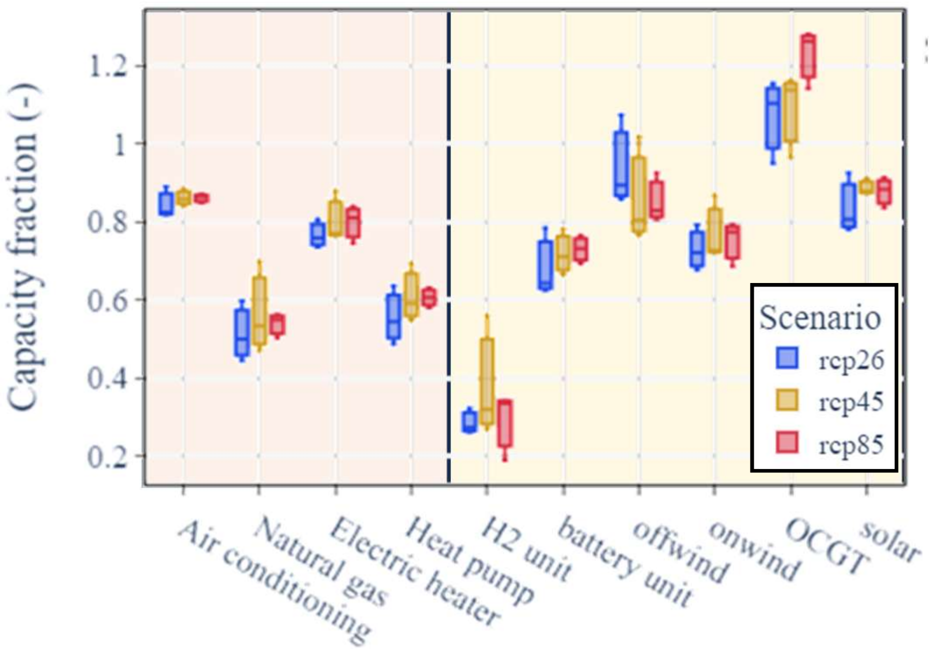
Results – 5% remaining emissions

- Retrofits occur in countries with larger heat demands (and in those with large cooling demands)
- The „retrofit-order“ is not strictly followed
  - e.g. in rcp8.5 DE receives significant retrofit and IT almost none
  - possibly due to geographical weather differences
- Greater decarbonisation may be possible through
  - more retrofits
  - more heat pumps



Results – 5% remaining emissions
Effect of retrofits



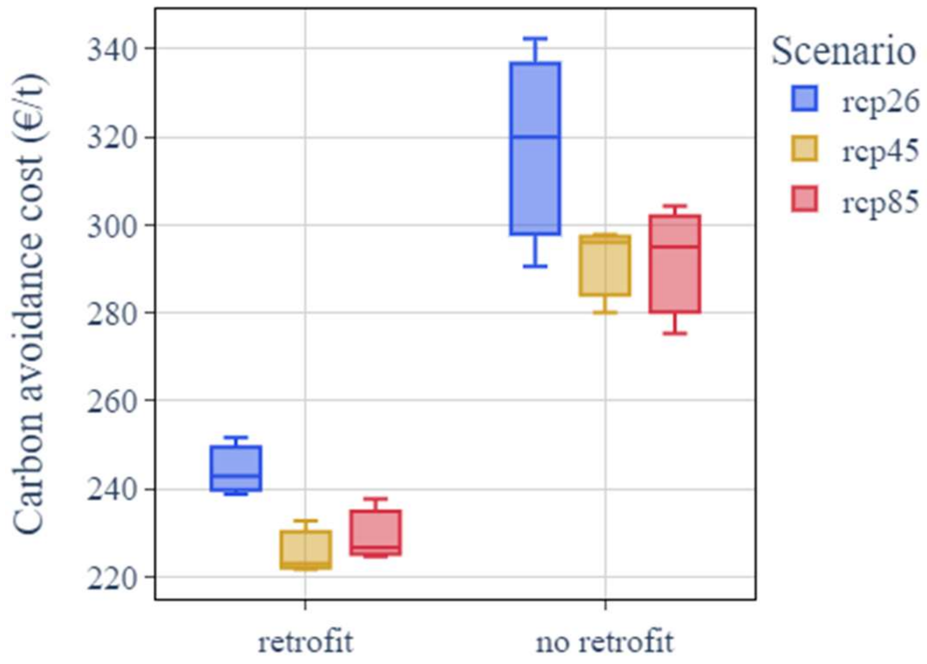


- $\Delta S_c = {S_c}^{retrofit} - {S_c}^{no\_retrofit}$

- $C_f = \frac{C^{retrofit}}{C^{no\_retrofit}}$

Results – 5% remaining emissions

- Retrofits enable roughly 20% lower carbon avoidance cost
- Possibly due to
  - Reduced demand
  - Reduced generation capacity requirement



Limitations, Conclusion & Outlook

Limitations

- Model development included **many** building level assumptions
- No consideration of regulatory frameworks
- Central planner perspective “shifts” retrofits across space and distorts results
- No CHP, thermal energy storage or transmission expansion option
- Temperature changes not reflected in heat pump efficiencies
  - Heat pump not available for cooling
- Climate change entails more than changes in temperatures
  - Capacity factors of hydro and thermal plants, transmission

Conclusion

- Sector coupled model enables better assessment of climate change effects on energy systems
- Retrofits…
  - reduced carbon avoidance cost
  - by reducing necessary supply capacities

Trade-off only visible in a sector coupled model
→ relevant for policies!

Outlook

- Addition of missing technologies
- Derive energy systems that are resilient against climate change effects
- What are no regret assets?

Thank you for your attention!

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